# NUMERICAL METHODS FOR SYNOPTIC COMPUTATION OF OCEANIC FRONTS AND WATER TYPE BOUNDARIES AND THEIR SIGNIFICANCE IN APPLIED OCEANOGRAPHY

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By

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water type boundaries from synoptic sea surface
temperature are described and the results shown and
compared. Changes of the position of the fronts and
their intensities are demonstrated. The computed fronts
are compared with known climatological water type and
oceanographic region boundaries. The nature of the
fronts and their significance in oceanographic analyses
and their effects to fisheries and naval problems are
pointed out.
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Abstract

Numerical methods for computation of oceanic fronts and water type boundaries from synoptic sea surface temperature are described and the results shown and compared. Changes of the position of the fronts and their intensities are demonstrated. The computed fronts are compared with known climatological water type and oceanographic region boundaries. The nature of the fronts and their significance in oceanographic analyses and their effects to fisheries and naval problems are pointed out.

## 1. Introduction

The environmental fronts in the oceans, comparable to the atmospheric fronts, delineate the boundaries of surface water types with different physical-chemical and biological properties. The oceanic fronts however have greater variety than the atmospheric ones. The sharpness of oceanic fronts can range from well-defined to undefinable transition regions which still constitute a dynamic front (current boundary). Some fronts are stable in space and time, some move considerably and change in intensity.

The knowledge of the positions, nature, intensity and dynamics of the fronts has a multitude of applications in fisheries, in naval problems and even in merchant navigation.

The fronts can be recognized by instrumental as well as by visual observations in many instances. The usual indicators of fronts are rapid sea surface temperature changes, water color changes, modified surface waves, accumulation of debris and sea smoke.

Numerous unsummarized observations of ocean fronts are available in ship logs. Inspired by the enthusiasm of Maury, one of the first international conferences on meteorological and navigational matters (Brussels 1854) agreed on voluntary observations of not only meteorological elements but also to observe and report upon any other natural phenomena which are encountered during the voyage. Much data on the observations of various types of discontinuities in sea surface temperature, water color and other frontal phenomena has accumulated

over these one hundred years. Some of the more interesting observations by British ships are reported in The Marine Observer. Unfortunately, no extensive working up of these frontal observations has been done in the past. The best climatological frontal charts appear to be those of Schott (1945) (Figure 1).

In this paper a brief review of some of the properties and problems of ocean fronts is summarized and attempts to compute the major fronts and surface water type boundaries by numerical means from synoptic oceanographic analyses are described.

## 2. Some properties of oceanic fronts

Griffiths (1965) discusses the definition of fronts in oceanography and finds that no precise definition is available, nor practicable. He accepts LaFond's (1961) definition and description of the oceanic front: "The leading edge of a border separating unlike water masses is called a front. Fronts can occur not only between water masses of different salinity but also between those differing in other properties, such as temperature."

The nature of the oceanic fronts can be quite variable as briefly mentioned in the introduction. LaFond (1961, 1963) and Griffiths (1965) give some physical and biological descriptions of fronts. More generalized frontal models with indication of subsurface thermal structure at fronts are given by Hela and Laevastu (1962).

Oceanic fronts are most often boundaries of different current systems (divergences/convergences) and thus are also boundaries of

different surface water types. Hence, they form boundaries between different natural regions of the oceans.

In the past some attempts have been made to divide oceans into natural regions, corresponding somewhat to the climatic regions of the land areas. The earlier divisions (Figures 2 to 4) were usually made on the basis of but a few characteristics. An attempt to revise these divisions on the basis of combined environmental (and also biological) characteristics is given in Figure 5. The names of these natural regions and their corresponding synonyms with reference to earlier authors are given in Table 1. In Table 2 similar comparative regions are grouped into larger groups.

The knowledge of the characteristics and environmental properties of these regions finds considerable application in a subjective description of the oceans and also in subjective oceanographic forecasting.

Some of the boundaries of the region on Figure 5 are poorly defined. Therefore there is a need to find a method for objective computation of these boundaries. The first attempts to do it numerically are reported below.

## 3. Numerical computation of ocean surface fronts

A number of different numerical approaches are available for computation of water type boundaries from synoptic analyses of temperature (SST) and surface currents; these are: a. SST SD pattern separation (small-scale SST anomalies), b. current stream function, c. SST and current stream function gradient calculations. The current

stream function gives only major boundaries in a smoothed fashion (Figure 6, 0 line in current stream function). The current stream function gradient calculations are essentially related to the SST gradient and the two computations thus give very similar results.

### 3.1 Pattern separation of sea surface temperature

A pattern separation of SST by scale has been developed by Holl (1963). The method consists of repeated application of a smoothing operator which reduces first the amplitudes of the shortest wave lengths and gradually affects longer and longer wave lengths. This technique has provided an objective method for quantitative separation of small-scale features from a large-scale pattern (Wolff, Laevastu and Hubert 1965).

Small-scale (SD) anomaly pattern of SST is given in Figure 7. This figure allows the determination of water type boundaries (dashed lines) to some extent, especially between the Labrador Current and Gulf Stream boundary. Figure 8 gives a more detailed part of the Gulf Stream area. The zero line (omitted in the plotting), between the negative and positive anomaly patterns presents the current boundary at the surface. When this technique is applied to a smaller-scale analysis, a more detailed picture is obtained. In major parts of the oceans where there are less pronounced SST gradients, the SD patterns do not define "fronts" in sufficient detail.

### 3.2 Surface temperature and current stream function gradient computations

The frontal location parameter introduced by Renard and Clarke (1965) and Clarke and Renard (1966) is a special application of a mathematical operator whose general utility exceeds that for which it was originally designed. The operator may be symbolically defined as

$$GG\,\xi \equiv -\nabla|\nabla\xi| \cdot \frac{\nabla\xi}{|\nabla\xi|} = -\nabla|\nabla\xi| \cdot n_\xi = \frac{\partial^2\xi}{\partial n^2_\xi}$$

where $\xi$ represents a dummy variable and $n_\xi$ is the unit vector in the direction of $\nabla\xi$. In words, $GG\,\xi$ is the second derivative of the parameter $\xi$, along its gradient. When the $GG\,\xi$ operator is calculated for parameters having continuous first and second derivatives but quasi first-order discontinuities, certain distinctive patterns are found. To facilitate understanding the uniqueness of $GG\,\xi$ in two dimensions, first consider its application in one direction. For simplicity, Figure 9 shows, schematically, the distribution of a parameter $\xi$, along an axis colinear with $\nabla\xi$, $\nabla|\nabla\xi|$, and $\nabla GG\,\xi$. The derived $|\nabla\xi|$ is shown in Figure 9b. In Figure 9c it will be noted that the maximum (positive) $GG\,\xi$ and minimum (negative) $GG\,\xi$ points coincide with the location of the quasi first-order discontinuity points, A, B, in Figure 9a ; the maximum $GG\,\xi$ is associated with the relatively higher value of the basic parameter, $\xi$. Note also that the zero $GG\,\xi$ point coincides with the location of the maximum value of the $|\nabla\xi|$ in Figure 9b.

Although a similar numerical approach is used for numerical analyses and forecasting of atmospheric fronts, there are some differences in interpreting the results. In the oceans, the center of the positive GG (SST) values presents in most cases the core of the warm current. The true current boundary is the northern edge (0 line) of the GG field (Figure 10a).

GG (SST) can also be computed for the colder side of the current. Figure 10b gives both the positive and negative GG computations. As seen from this figure, the features on opposite sides of a front do not necessarily have the same intensity. The positive (warm) side is computed at FNWF on an operational basis twice daily.

## 4. <u>Some observations on the behavior of oceanic fronts and use of frontal analyses</u>

The fronts can move rapidly and change their sharpness, as a study of an oceanic front along 155°W (Laevastu and Rothchild) demonstrates (Figure 10c). As can be seen from this figure, this particular front is better delineated by salinity than by temperature. Synoptic surface salinity analyses are however not available.

Fronts at the surface are also related to subsurface thermal structure changes (LaFond 1963, Hela and Laevastu 1962). The major fronts, which are clearly distinguishable in the 200 meter temperature distribution, also show at this depth seasonal movements (Dietrich 1964) (Figure 10d), but these dislocations are somewhat smaller than at the surface.

Comparing Figures 1 and 5 with the synoptic GG SST fields it becomes apparent that some of the major fronts are remarkably well defined. However some fronts and water type boundaries, especially in the eastern parts of the oceans, are ill defined by surface analysis and on the other hand some of the boundaries on Figure 5 require revision. This can be done when a full year of synoptic GG SST fields is available.

The major fronts are relatively stable, especially in the western parts of the oceans and vary but little seasonally (Figures 10a and 10e). Other fronts show seasonal variations. In general the lower latitude fronts show considerable seasonal shifts. There are also considerable variations in the intensity of fronts over short periods of time (a few days).

During the winter season (January to March) the front off Baja California and the eastern ends of the fronts around 35$^{\circ}$N in both oceans were well defined, but appear much stronger during the late spring (Figure 10e). It has been suggested (Dr. Flittner, personal communication) that the appearance of albacore off the West Coast might be related to this front.

The knowledge of ocean fronts finds a number of applications in fisheries as well as in naval problems. Some specific studies on the influence of the frontal zones on sonar problems have been initiated at NEL as well as at FNWF and fisheries applications are pursued especially at the BCF Tuna Resources Laboratory in La Jolla.

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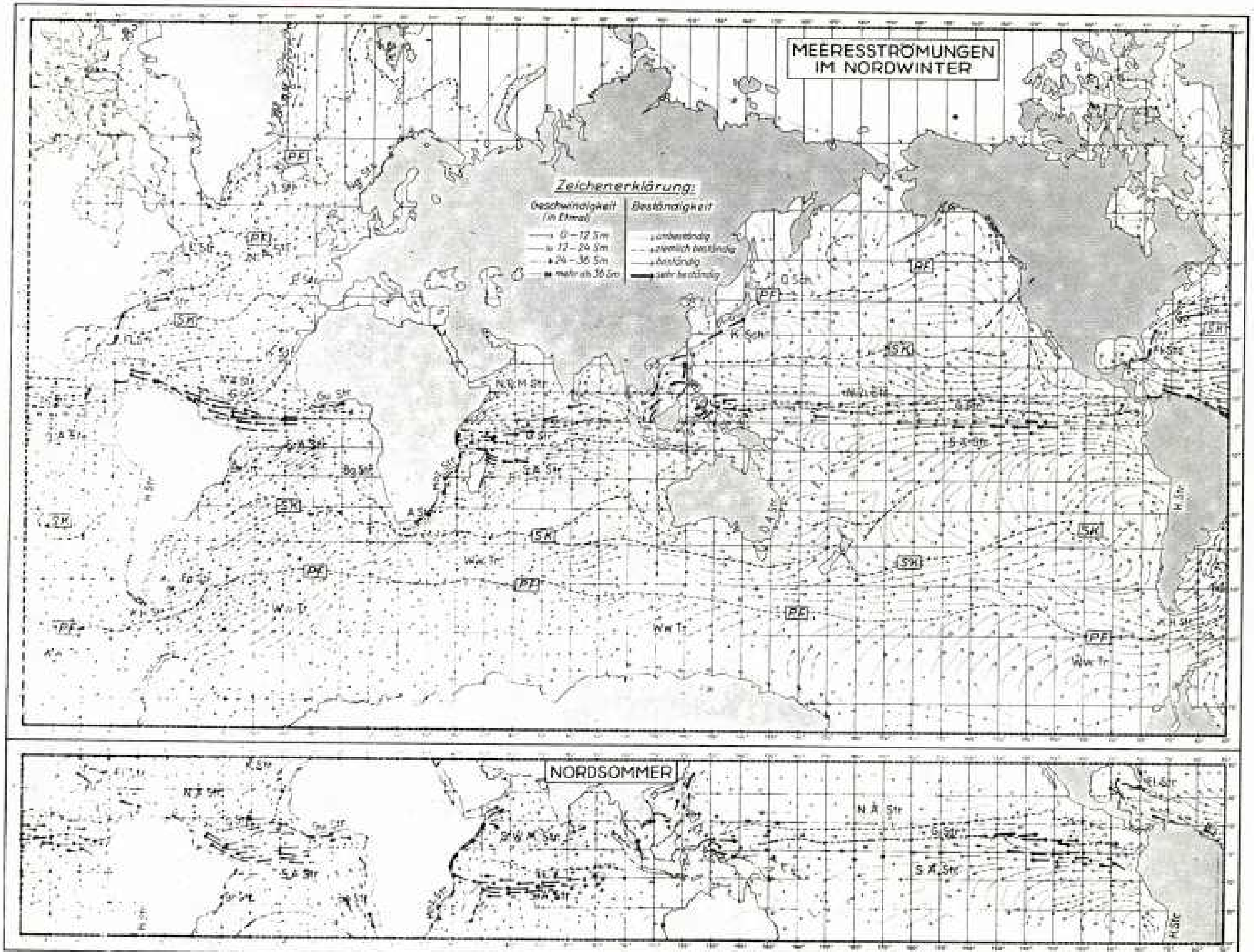
List of Figures and Tables




**Erklärung der Abkürzungen.**

| | | |
|---|---|---|
| A. Str. | = | Agulhasstrom |
| Bg. Str. | = | Benguellastrom |
| Br. Str. | = | Brasilstrom |
| Fa. Str. | = | Falklandstrom |
| Fl. Str. | = | Floridastrom |
| G. Str. | = | Äquatorialer Gegenstrom |
| Go. Str. | = | Golfstrom |
| Gu. Str. | = | Guineastrom |
| H. Str. | = | Humboldtstrom |
| I. Str. | = | Irminger Strom |
| K. Str. | = | Kanarenstrom |
| K.H. Str. | = | Kap Hoorn-Strom |
| K. Sch. | = | Kuro Schio |
| L. Str. | = | Labradorstrom |
| Moz. Str. | = | Mozambiquestrom |
| N.A. Str. | = | Nordostatlantischer Strom |
| N.Ä. Str. | = | Nordäquatorialstrom |
| Ng. Str. | = | Norwegischer Strom |
| NO.M. Str. | = | Nordostmonsunstrom |
| O.A. Str. | = | Ostaustralischer Strom |
| O. Sch. | = | Oya Schio |
| P.F. | = | Polarfront |
| P. Str. | = | Portugalstrom |
| S.Ä. Str. | = | Südäquatorialstrom |
| S K | = | Subtropische Konvergenz |
| Som. Str. | = | Somalistrom |
| S.W.M. Str. | = | Südwestmonsunstrom |
| Ww.Tr. | = | Westwindtrift |

**FIGURE 1**

**SURFACE CURRENTS AND CURRENT BOUNDARIES, NORTHERN HEMISPHERE (AFTER SCHOTT 1945)**

Figure 3. Natural Regions of the Oceans (after G. Schott)

Atlantic Ocean

1. Atlantic North Pole Region
2. North Atlantic Sub-polar Region
3. North Atlantic Current Region
4. Newfoundland Region
5. Gulf Stream and West Indian Region
6. Sargasso Sea
7. Morocco Region
8. Cape Verde Region
9. Guinea Region
10. Brazilian Region
11. Ascension Region
12. Southwest African Region
13. Patagonian Region
14. South Atlantic Medium Latitudes
15. South Sub-polar Region
16. South Polar Region

Pacific Ocean

17. East Asian Coastal Region
18. Alaska Gyral Region
19. North Pacific Medium Latitudes
20. Californian Region
21. Japanese Region
22. North Pacific Tradewind Region
23. Mexican Region
24. Malayan Sea Region
25. Pacific Equatorial Region
26. South Pacific Islands Region
27. Galapagos Region
28. South Indo-Pacific Medium Latitudes

Indian Ocean

29. Arabian Sea Region
30. Bay of Bengal Region
31. Indian Equatorial Region
32. Mozambique Region
33. Mauritius Region
34. Northwest Australian Region
35. Southwest Australian Region

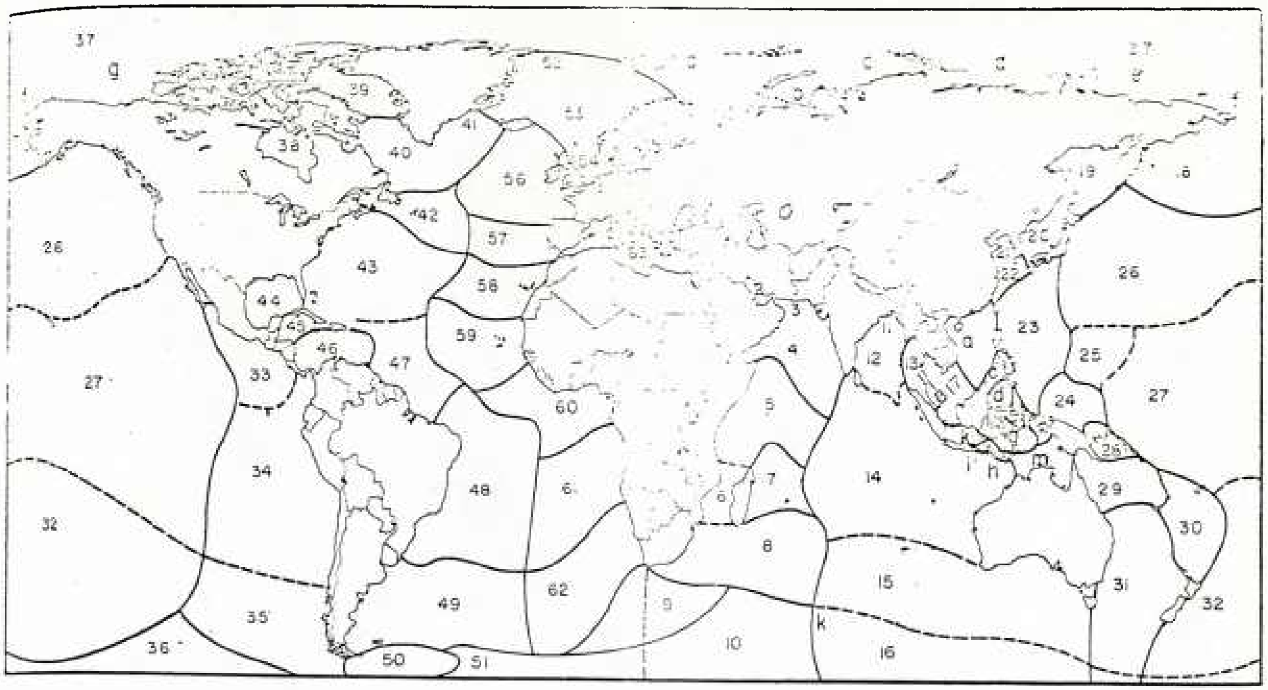



Figure 2 Divisions of oceans and seas (Wüst 1936, 1939)
(For the name of the regions, see Table 1)

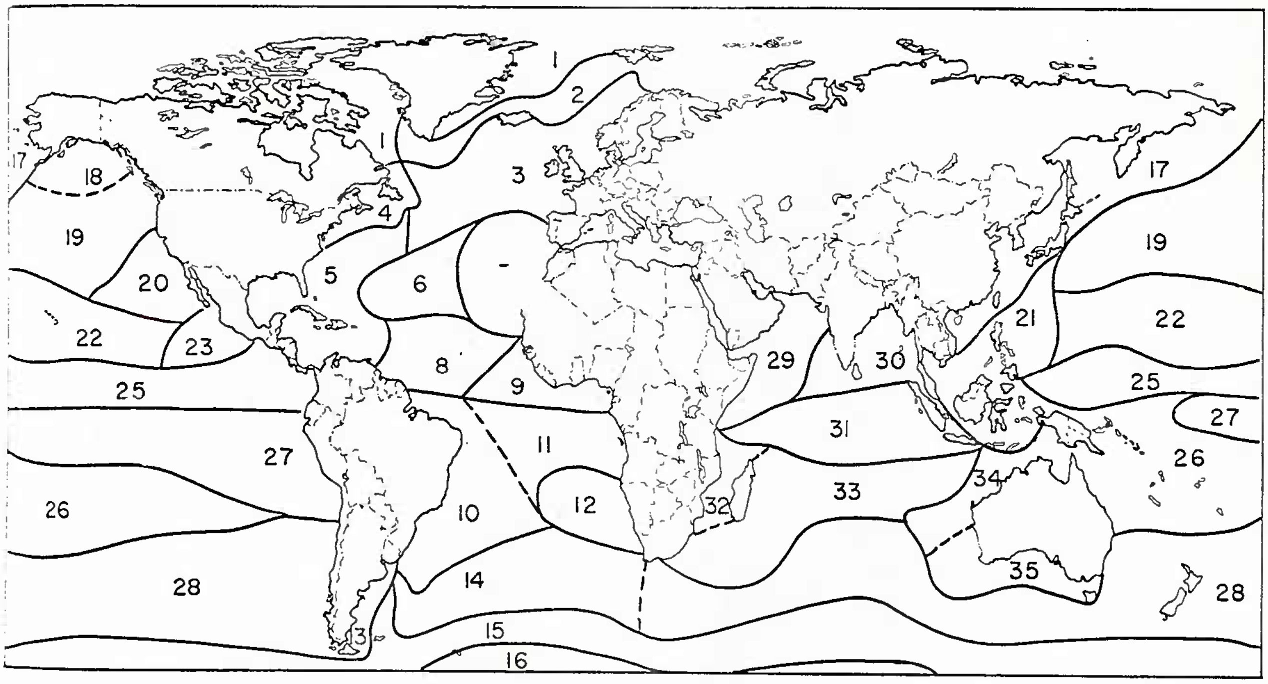



Figure 3 Natural regions of the oceans (after Schott)

Figure 4. Regional Structure of the Oceans (after Dietrich and Kalle)

| | | | |
|---|---|---|---|
| P | | Trade - Current Region | Throughout the year steady to very steady currents toward west. |
| | Pe- | with strong component towards the equator. | |
| | Pw- | clear westerly current. | |
| | Pp- | with strong component towards the poles. | |
| E | | Equatorial Current Region | At times or throughout the year easterly currents close to the equator. |
| M | | Monsoon Current Region | Regular reversal of the current in spring and autumn. |
| | Mt- | Lower latitudes (small changes in surface temperature). | |
| | mg- | Medium and higher latitudes (great changes in surface temperature). | |
| R | | Horse - Latitude Region | At times or throughout the year weak currents with varying direction. |
| F | | Free - Beam Region | Throughout the year strong currents as runoff from Trade-Current Region. |
| W | | Westwind - Drift Region | Throughout the year varying easterly currents. |
| | We- | on the equator side of the oceanic polar front. | |
| | Wp- | on the pole side of the oceanic polar front. | |
| B | | Polar Region | At times and throughout the year covered with ice. |
| | Be- | Outer polar regions; covered with pack ice during winter and spring. | |
| | Bj- | Inner polar regions; covered with ice throughout the year. | |

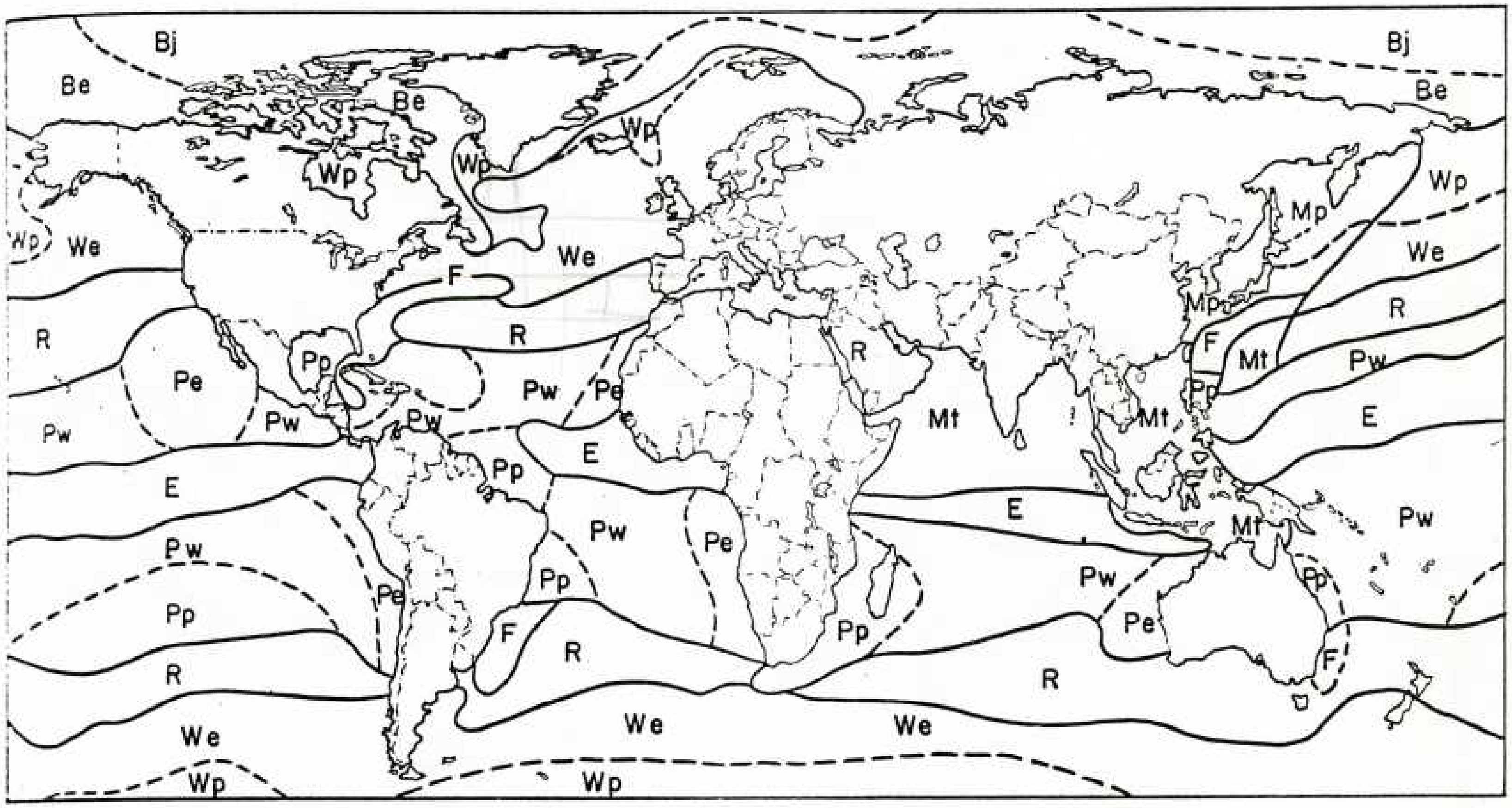
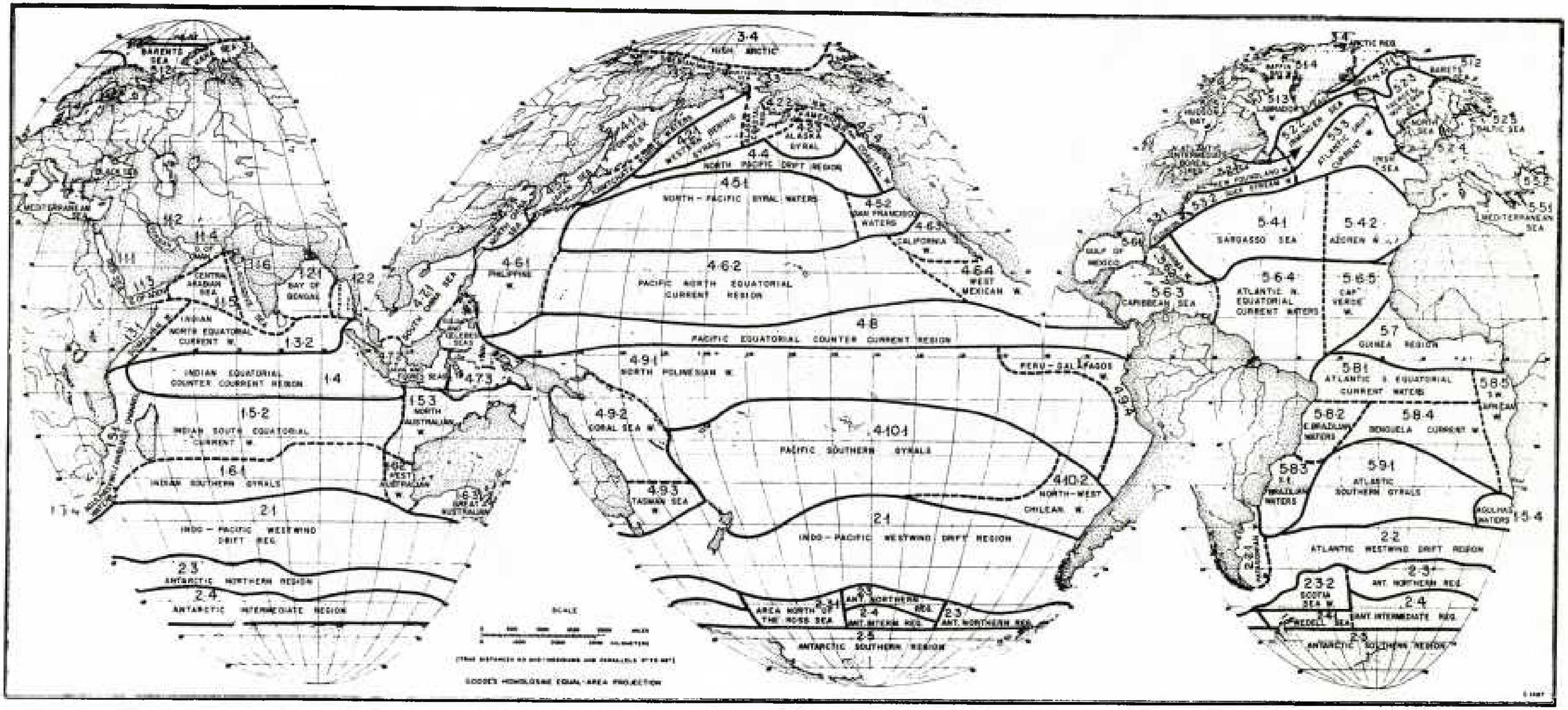
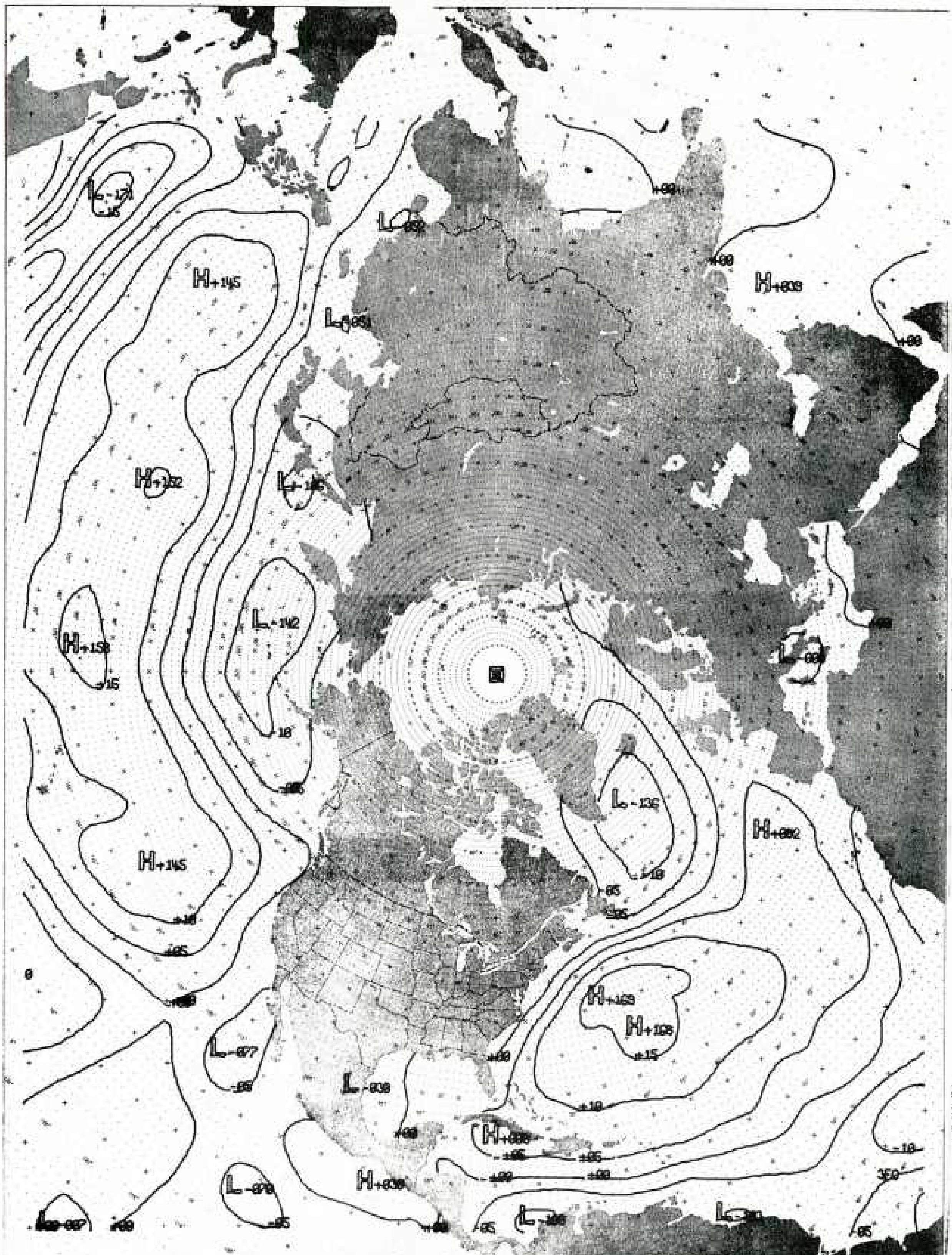



Figure 4 Regional structure of the oceans (after Dietrich and Kalle)

Figure 5 NATURAL REGIONS OF THE OCEANS



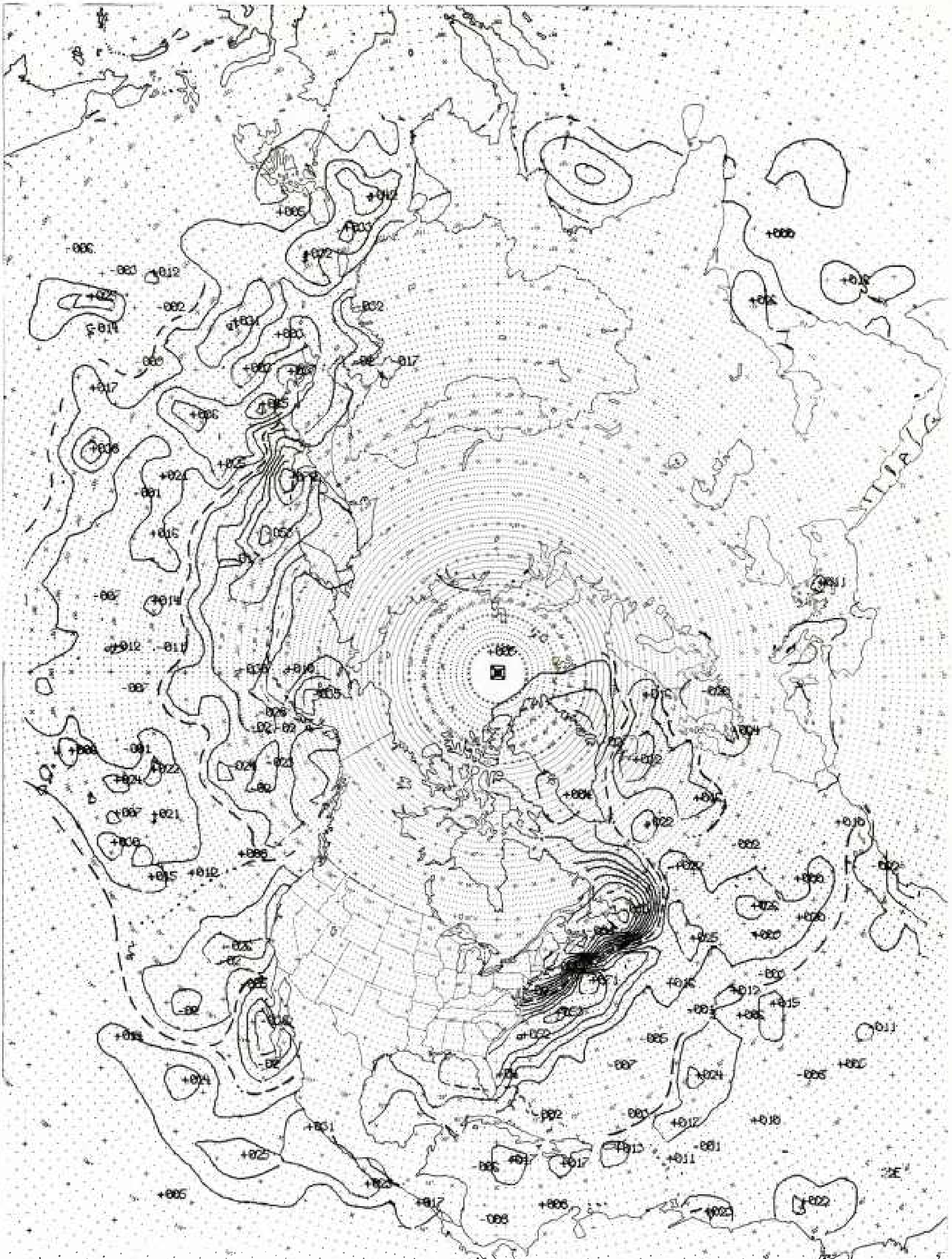

BOUNDARIES OF THE REGIONS
BOUNDARIES OF THE SURFACE WATERS



SURFACE CURRENT STREAM FUNCTION 12Z 29 APRIL 1966

PROJECTION: POLAR STEREOGRAPHIC–TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FIGURE 6



# SEA SURFACE TEMPERATURE (SST) SD PATTERN ON 12Z 21 MAY 1965

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

## FIGURE 7

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6-B

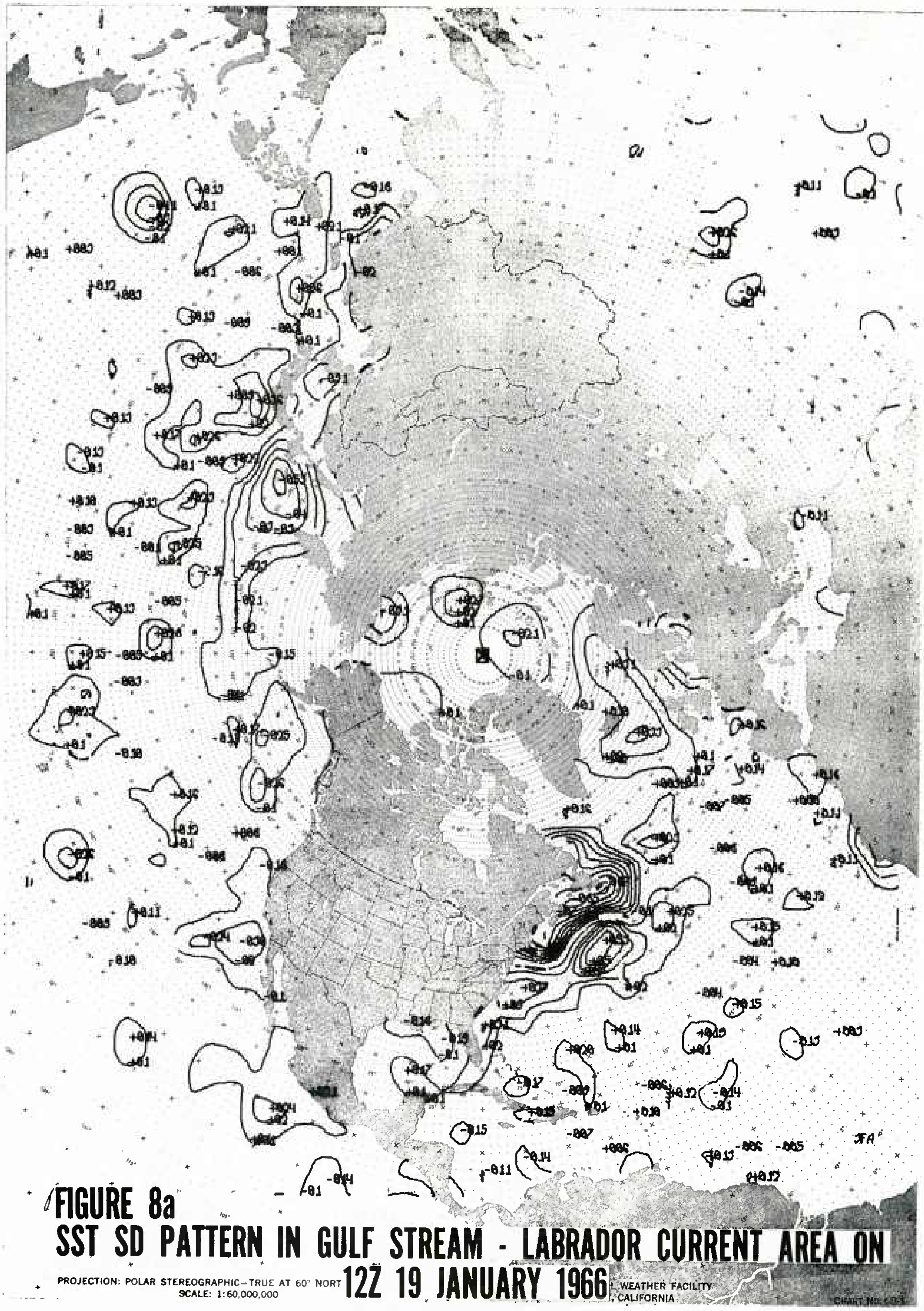



FIGURE 8a

SST SD PATTERN IN GULF STREAM - LABRADOR CURRENT AREA ON 12Z 19 JANUARY 1966

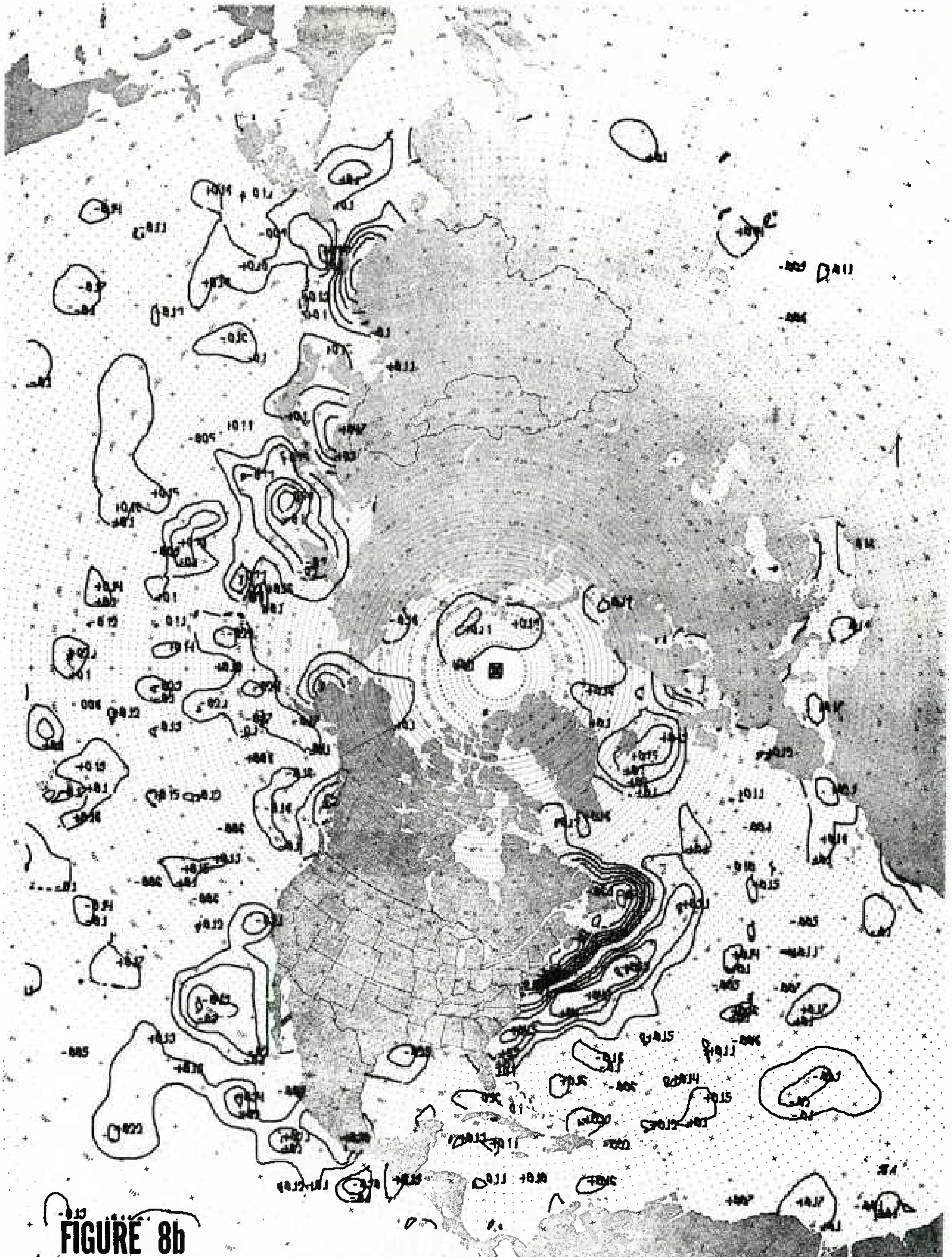



**FIGURE 8b**

**SST SD PATTERN IN GULF STREAM - LABRADOR CURRENT AREA ON 00Z 31 JANUARY 1966**

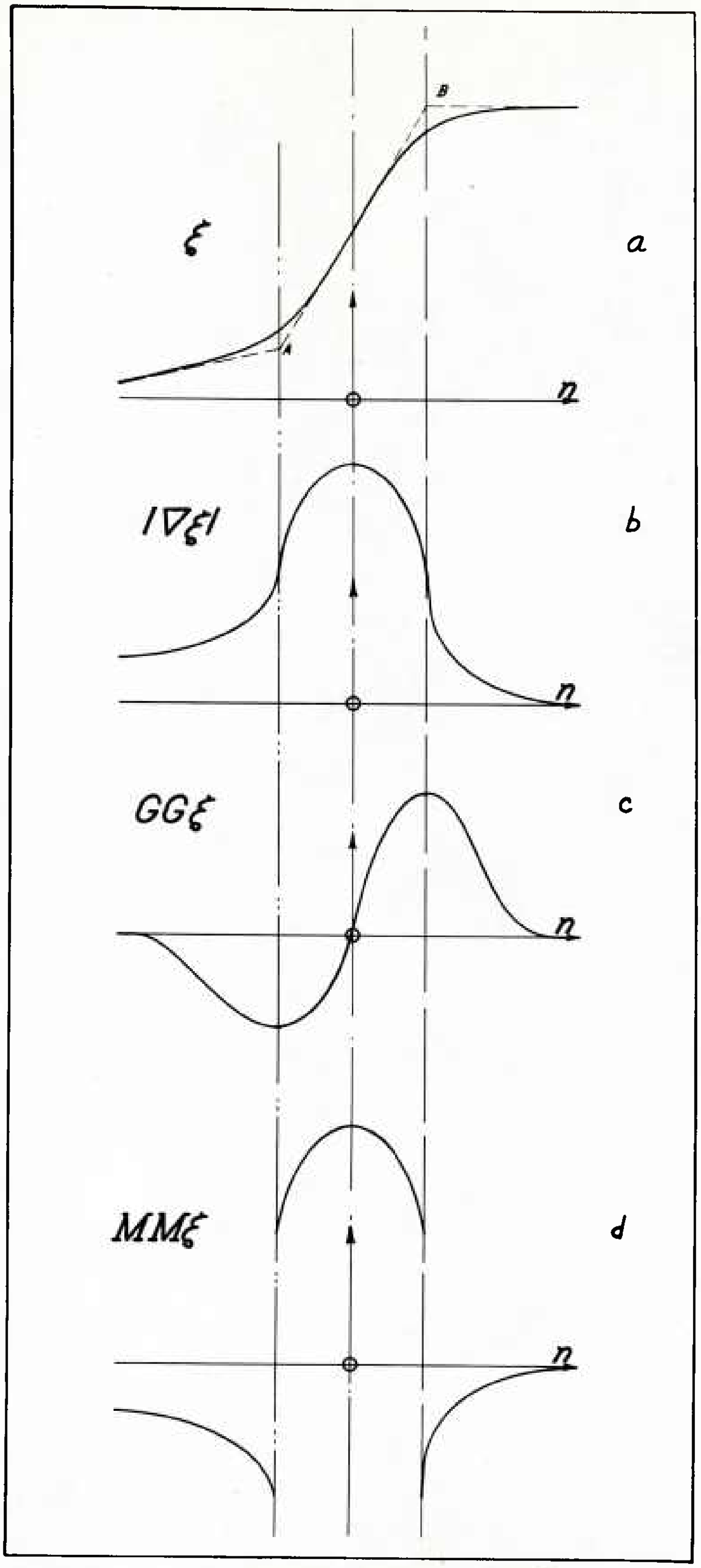
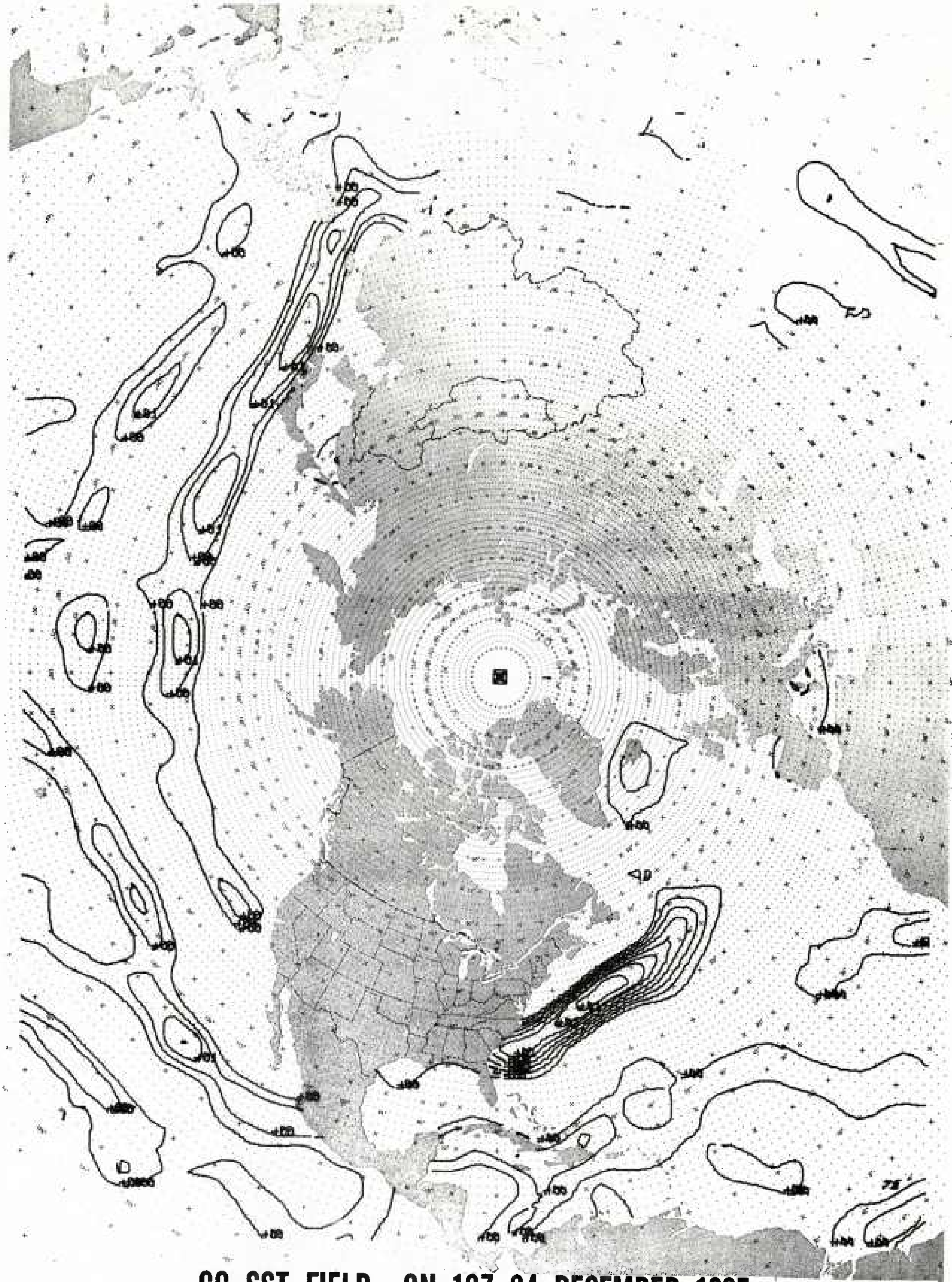



Figure 9 Geometrical relationships involved in the GG parameter



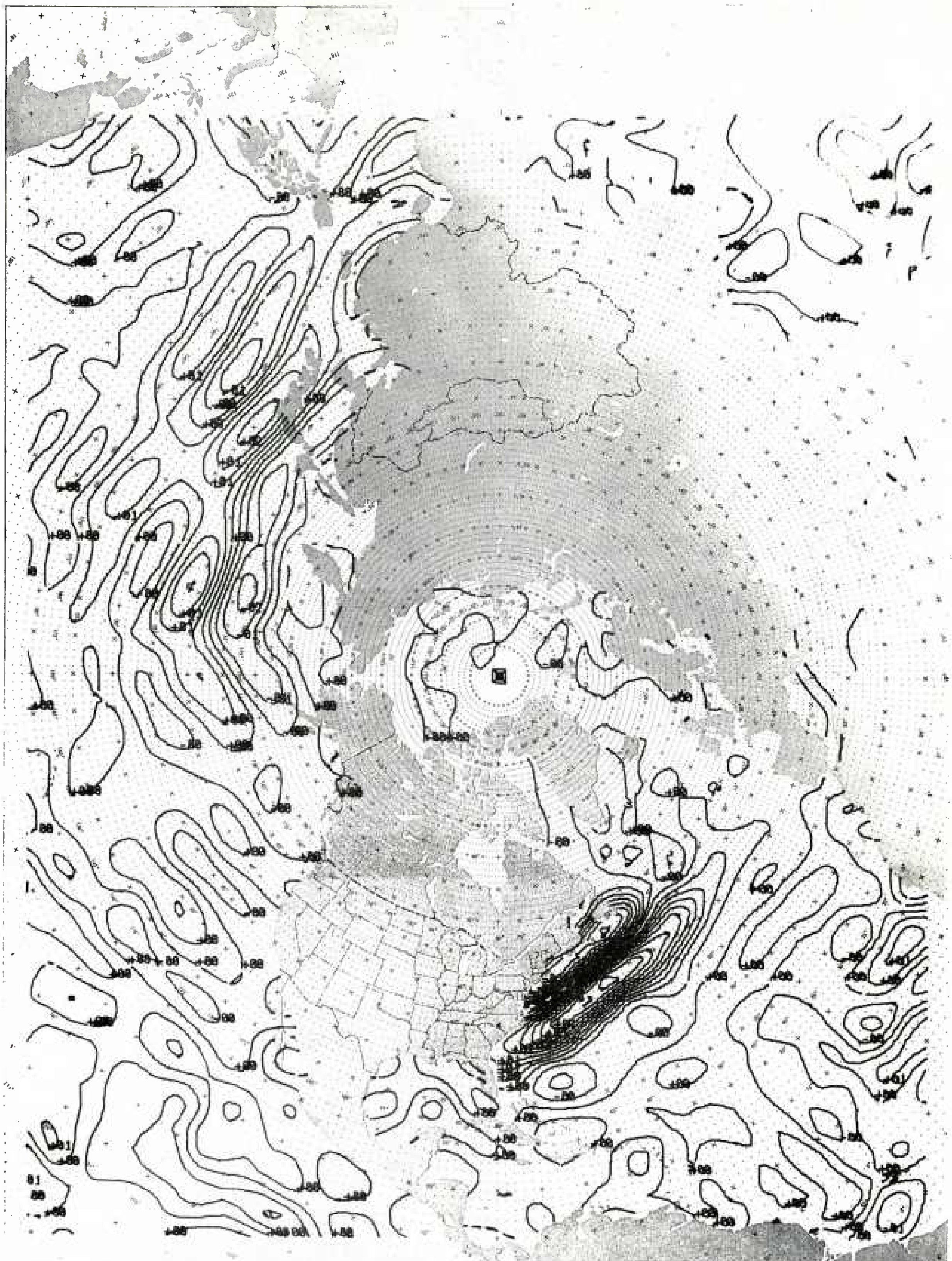
GG SST FIELD ON 12Z 24 DECEMBER 1965

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITU
SCALE: 1:60,000,000

FIGURE 10a

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1



NEGATIVE AND POSITIVE GG SST FIELDS ON 12Z 01 DECEMBER 1965

PROJECTION: POLAR STEREOGRAPHIC–TRUE AT 60° NORTH LAT
SCALE: 1:60 000,000

FIGURE 10b

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1

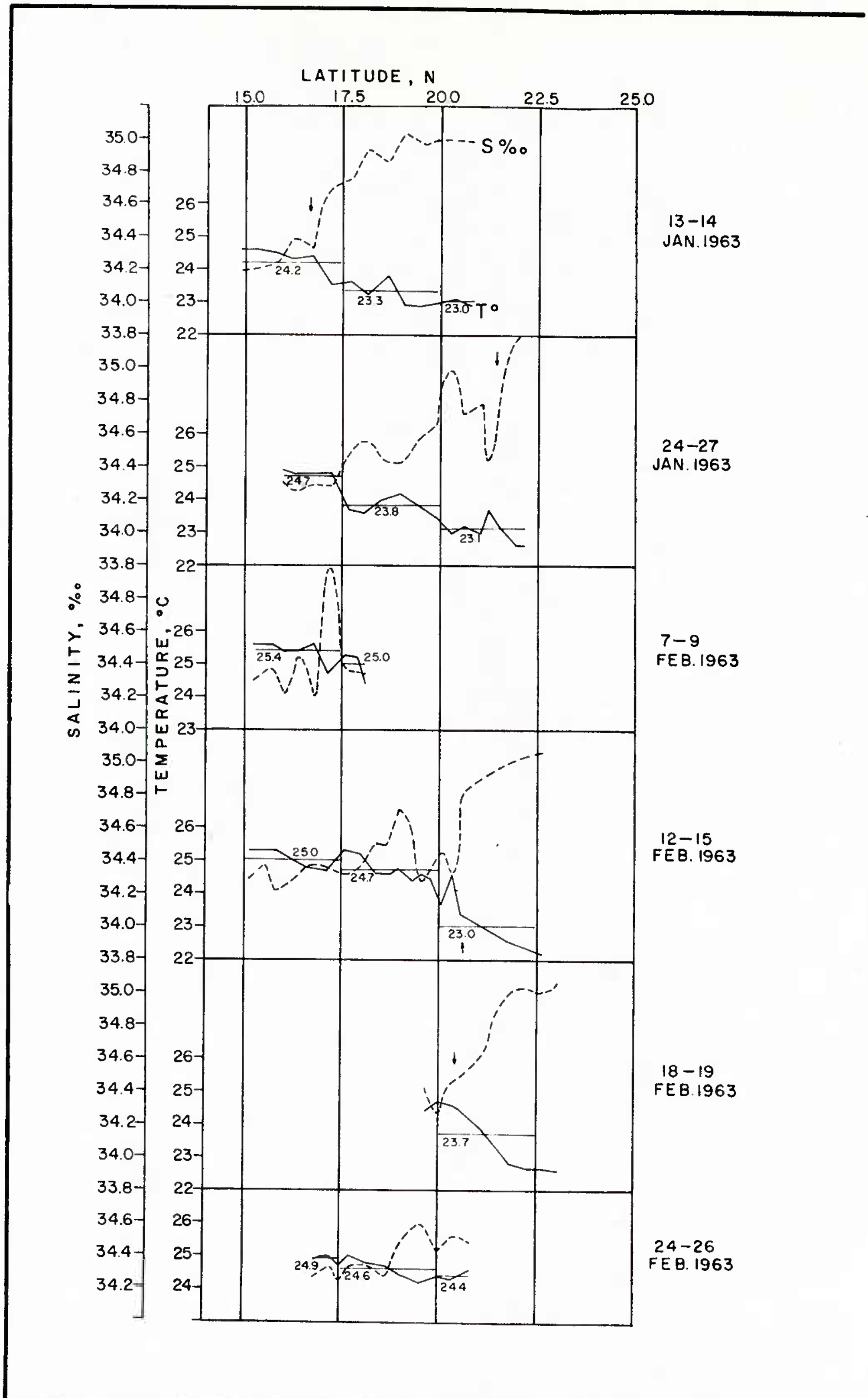



FIGURE 10c SURFACE SALINITY AND TEMPERATURE ALONG 155°W ON 13 JAN TO 26 FEB 1966

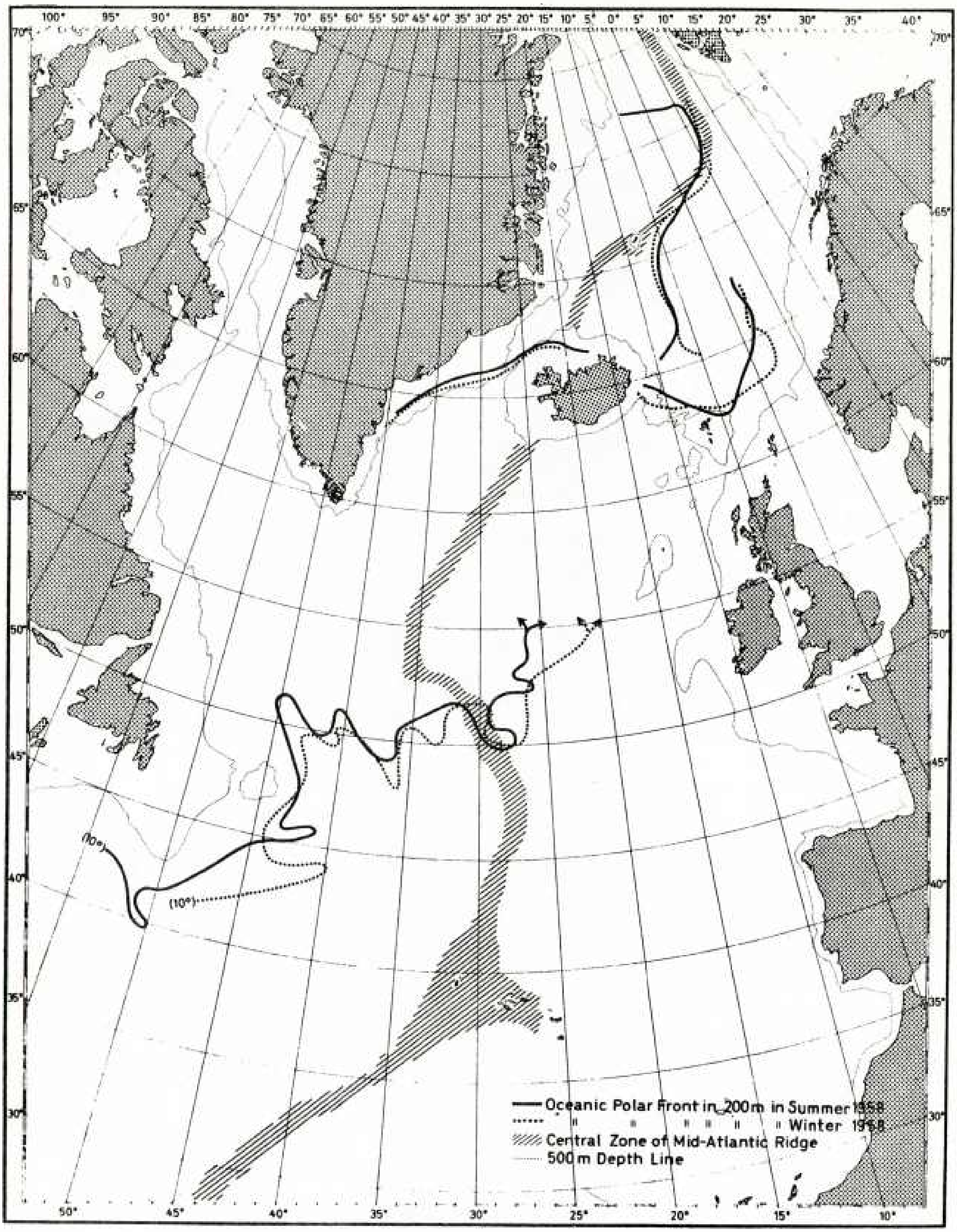
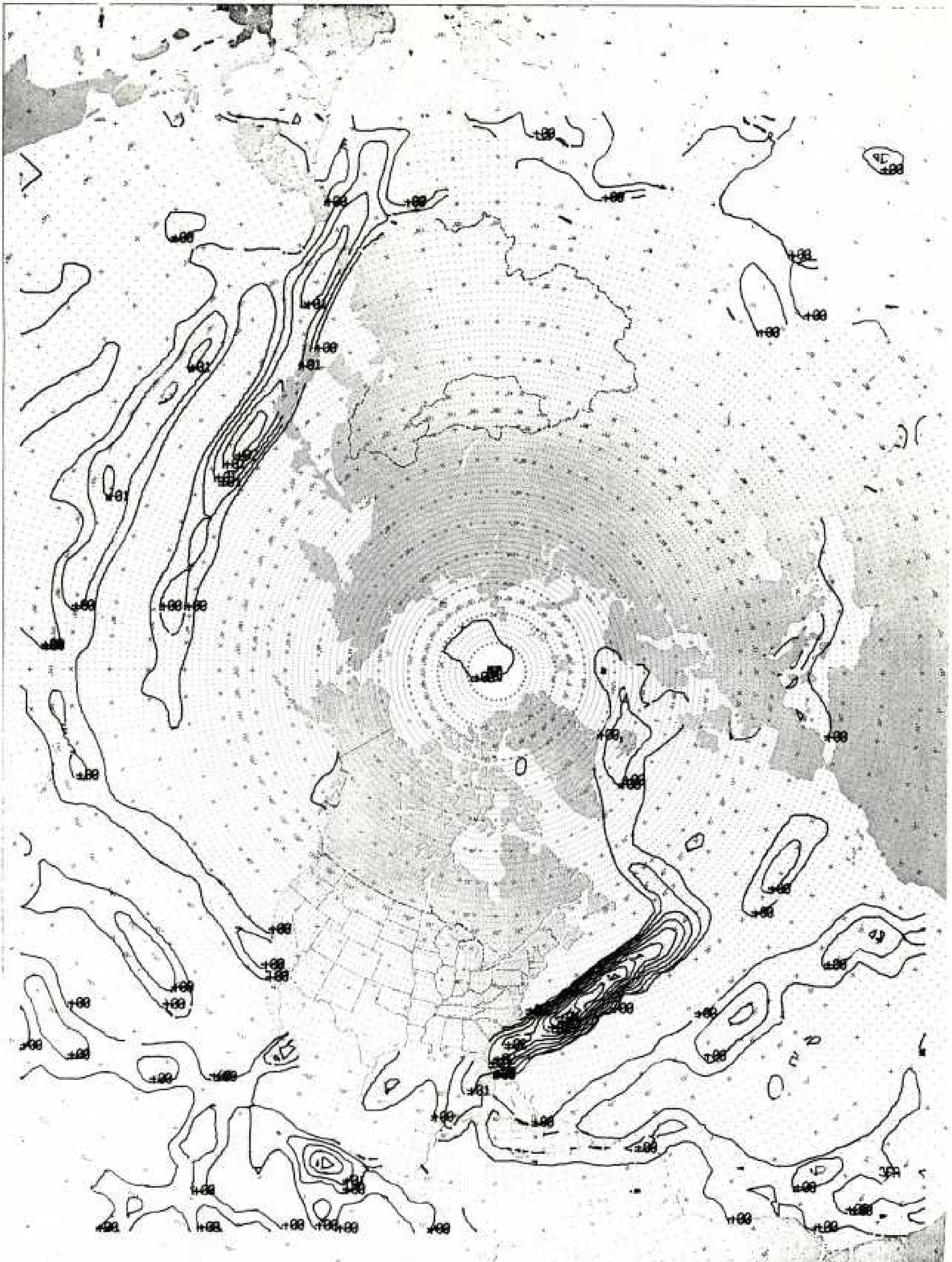



Figure 10d The oceanic polarfront in the northern North Atlantic in 200 m depth in late winter and late summer 1958



GG SST FIELD ON 00Z 03 MAY 1966

PROJECTION: POLAR STEREOGRAPHIC–TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FIGURE 10e

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1

Table 1

NATURAL REGIONS OF THE OCEANS

Present and past divisions (see Figures 2 to 5)

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrogr. Bureau, (IHB) |
|---|---|---|
| 1.0 Indian Ocean Monsoon Regions | ) Monsoon Current Region (DK) ) (partly) | |
| 1.1 Arabian Sea Region (with Red Sea and Persian Gulf) | ) Arabian Sea Region (S); ) Arabian Sea (W) | |
| 1.1.1 Red Sea N and S parts | N part Horse Lat. Region (DK) | Red Sea (IHB) (W) |
| 1.1.2 Persian Gulf | | Gulf of Iran (IHB); Persian G. (W) |
| 1.1.3 Gulf of Aden | | Gulf of Aden (IHB) (W) |
| 1.1.4 Gulf of Oman | | Gulf of Oman (IHB) (W) |
| 1.1.5 Central Arabian Sea | | Arabian Sea (IHB) (W) |
| 1.1.6 Laccadive Sea (Indian Western Coastal Waters | Included in Bay of Bengal Region (S) | Laccadive Sea (IHB) |
| 1.2 Bay of Bengal Region | Bay of Bengal Region (S) | |
| 1.2.1 Bay of Bengal | | Bay of Bengal (IHB) (W) |
| 1.2.2 Andaman Sea | Burma Sea | Andaman or Burma Sea (IHB) |
| 1.3 Indian Ocean North-Equatorial Current Region | Include in Monsoon Current Region (DK) Somali Sea (W) | |
| 1.3.1 Somali Waters | Included in Arabian Sea Region (S) | |
| 1.3.2 Indian Ocean North-Equatorial Current Waters | Indian Equatorial Region (S) | |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|
| 1.4 Indian Ocean Equatorial Counter Current Region | Equatorial Current Region (DK) | Indian-Australian Sea (W) |
| 1.5 Indian Ocean South-Equatorial Current Region | Mauritius Region (S)<br>Trade Current Region (DK) | |
| 1.5.1 Mozambique Strait | Mozambique subregion (S)<br>Mozambique Strait (W) | Mozambique channel (IHB)(W) |
| 1.5.2 Indian Ocean South-Equatorial Current Waters | Mascarene Sea (W) and Indian-Australian Sea (W) | Mascarene Sea (W) and part of Indian-Australian Sea (W) |
| 1.5.3 North Australian Waters Included: Timor Sea and Arafura Sea | N.W. Australian Region (S) | Alfuren Sea with Gulf of Carpentaria (W)<br>Timor and Arafura Seas (IHB) |
| 1.5.4 Agulhas Waters | Free-Beam Region (DK); Cap Sea(W) | |
| 1.6 Indian Ocean Horse Latitude Region | Horse Latitude Region (DK): South Indo-Pacific Medium Latitudes (S) | Includes Madagascar Sea (W) |
| 1.6.1 Indian Ocean Southern Gyrals Waters | Includes Madagascar Sea (W) | |
| 1.6.2 West Australian Waters | Indian Australian Sea (W) | |
| 1.6.3 Great Australian Bight | S.W. Australian Region (S); South Australian Sea (W) | Great Australian Bight (IHB) (W) Includes Bass Strait (IHB) |
| 2.0 Westwind Drift Regions | ) Westwind Drift Region (DK);<br>) South Subpolar Region (S);<br>) South Polar Sea (W) and | |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrog. Bureau (IHB) |
|---|---|---|
| ..1 Indo-Pacific Westwind Drift Region | ) South Pacific Sea (W) | |
| 2.2 Atlantic Westwind Drift Region | | |
| 2.2.1 Patagonian Waters | Patagonian Region (S); Argentinian Sea (W) | Includes Rio de la Plata (IHB) |
| 2.3 Antarctic Northern Region | South Polar Region (S); South Polar Sea (W) | Includes Bellingshausen Sea (W) |
| 2.3.1 Area North of the Ross Sea | | |
| 2.3.2 Scotia Sea and South Georgian Area | South Antillen Sea (W) | South Antillen Sea (W) |
| 2.4 Antarctic Intermediate Region | | |
| 2.4.1 Wedell Sea | Wedell Sea (W) | Wedell Sea (W) |
| 2.5 Antarctic Southern Region | | |
| 3.0 Arctic Region | North Pole Region (S); North Polar Sea (W); Polar Region (DK) | |
| 3.1 Kara Sea | Kara Sea (W) | Kara Sea (IHB) (W) |
| 3.2 North Siberian Waters | Nansen Sea; Nordenskjöld Sea and East Siberian Sea (W) | Includes Laptev (or Nordenskjöld) Sea (IHB)(W) and East Siberian S (IHB)(W), W.Siberian S.(W) |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst, 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|
| 3.3 Chucktschee and Beaufort Seas | Chuktschee and Beaufort Seas (W) | Chuckchi Sea and Beaufort Sea (IHB) (W) and Canadian Straits (W) |
| 3.4 High Arctic | Inre Polar Region (DK) | Arctic Ocean (IHB) |
| 4.1 Kamtchatka Region | Monsoon Current Region (higher Lat.) (DK) East Asian Coastal Region (S) | |
| 4.1.1 Okhotsk Sea | Okhotsk Sea (W) | Sea of Okhotsk (IHB) (W) |
| 4.1.2 Kamtchatka - Kurile Waters | | |
| 4.2 Alaska Region | Westwind Drift Region (DK); Alaska Gyral Region (S); Bering Sea (W) | |
| 4.2.1 Western Bering Gyral | | ) Bering Sea (IHB) (W) |
| 4.2.2 Alaska Coastal Waters | | ) |
| 4.2.3 Alaska Gyral | | ) (Partly) Gulf of Alaska ) (IHB) and the Coastal ) Waters of S. Alaska and |
| 4.2.4 NW American Coastal Water | North Pacific Sea (W) | ) British Columbia (IHB) |
| 4.3 North China and Japan Seas Reg. | Monsoon Current Region (DK); East Asian Coastal Region (S) | |
| 4.3.1 North China Sea | Iung Hai and Hwang Hai; E.China Sea (W) | East China Sea with Yellow Sea (W) Yellow Sea and Eastern China S.(IHB) |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical Regions by Wüst, 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|
| 4.3.2 Sea of Japan | Japan Sea (W) | Japan Sea (IHB) (W) |
| 4.4 North Pacific Drift Region | Westwind Drift Region (DK): North Pacific Medium Latitudes (S) | |
| 4.5 Central North Pacific Region | Horse Latitude Region (DK); North Pacific Sea (W) | |
| 4.5.1 North Pacific Gyral Waters | North Pacific Sea (W) | |
| 4.5.2 S. Francisco Waters | Central Pacific Sea (W) | |
| 4.6 Pacific North Equatorial Current Region | Trade Current Region (DK); North Pacific Tradewind Region (S); Central Pacific Sea (W) | |
| 4.6.1 Philippine Waters | Philippine Sea (W) | Philippine Sea (IHB) |
| 4.6.2 Pacific North Equatorial Current Waters | | |
| 4.6.3 California Coastal Waters | California Region (S) | Includes Gulf of California (IHB) |
| 4.6.4 West Mexican Waters | Mexican Region (S);Guatemala Sea (W) | |
| 4.7 Indonesian Region | Monsoon Current Region (DK); Japanese Region (S); Austral-Asiatic Mediterranean Sea (W) | |
| 4.7.1 South China Sea | Nan Hai South China Sea (W) and Malaian Sea (W) | South China Sea Gulf of Siam and Mallacea and Singapore Straits (IHB) (W) |
| 4.7.2 Java and Flores Seas | Java, Flores, Seas and Makassar Strait (W) | Java, Flores, Bali and Savu Seas (and Makassar Strait) (IHB) (W) |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst, 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|
| 4.7.3 Sulu and Celebes and Banda Seas | Sulu, Molucca, Celebes, Ceram and Banda Seas (W) | Sulu, Celebes, Molukka, Ceram and Banda Seas (IHB) (W) |
| 4.8 Pacific Equatorial Counter Current Region | Equatorial Current Region (DK); Pacific Equatorial Region (S) | |
| 4.9 Pacific Equatorial Current Region | Trade Current Region (DK); Pacific Equatorial Region (S) | |
| 4.9.1 North Polinesian Waters | Carolina and Salomon Seas (W) | Includes Bismarck Sea (IHB) |
| 4.9.2 Coral Sea | Coral Sea (W) | Coral Sea (IHB) (W) |
| 4.9.3 Tasman Sea | Tasman Sea (W) | Tasman Sea (IHB) (W) |
| 4.9.4 Peru-Galapagos Waters | Galapagos Region (S); Peruvian Sea (W) | |
| 4.10 Pacific Southern Gyrals Region | Trade Current Region and Horse-Latitude Region (DK); South Indo-Pacific Medium Latitudes (S); Central Pacific Sea (W) | |
| 4.10.1 Pacific Southern Gyrals | | |
| 4.10.2 North-West Chilean Waters | South Chilean Sea (W) | |
| 5.1 Atlantic Subarctic Regions | Polar Region (DK); Atlantic North Pole Region (S) | |
| 5.1.1 East Greenland Waters | Greenland Sea (W) | Greenland Sea (IHB) (W) |
| 5.1.2 Barents Sea | Barents Sea (W) | Barentsz Sea (IHB) |
| 5.1.3 Labrador Waters | Labrador Sea (W) | Davis Strait and Labrador Sea (IHB)<br>Labrador Sea (W) |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|
| 5.1.4 Baffin Bay | Baffin Sea (W) | Baffin Bay (IHB); Baffin Sea (W) |
| 5.1.5 Hudson Bay | Hudson Sea (W) | Hudson Sea (W);Hudson Bay and Strait (IHB) |
| 5.2 North Atlantic Intermediate Boreal Region | Westwind Drift Region (DK); N. Atlantic Subpolar Region (S) | |
| 5.2.1 New Foundland Waters | New Foundland Region (S); (W) | Includes Bay of Fundy and Gulf of St. Lawrence (IHB)(W) |
| 5.2.2 Irminger Sea | Irminger Sea (W) | Irminger Sea (W) |
| 5.2.3 Norwegian Sea-Faeroes Waters | North European Sea or Norwegian Sea (W) | Norwegian Sea (IHB) (W) |
| 5.2.4 North Sea, Irish Sea and English Channel | North Sea (W) | (Includes also Skagerrak and British Channel) (IHB) (W) |
| 5.2.5 Baltic Sea | Baltic Sea (W) | Baltic Sea (Includes Kattegat) (IHB) (W) |
| 5.3 Gulf Stream - Atlantic Drift Current Region | Free-beam Region and Westwind Drift Region (DK) North Atlantic Current Region (S); New Foundland Sea and West European Sea (W) | |
| 5.3.1 Florida Waters | | |
| 5.3.2 Gulf Stream Waters | Gulf Stream and West Indian Region (S) | |
| 5.3.3 Atlantic Drift Current Waters | | Includes Bay of Biscay (IHB)(W) |
| 5.4 Central North Atlantic Region | Horse Latitude Region (DK) | |

| | Name of Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrog. Bureau, (IHB) |
|---|---|---|---|
| | 5.4.1 Sargasso Sea | Sargasso Sea Region (S); (W); North American Sea (W); | Sargasso Sea (W) |
| | 5.4.2 Azoren Waters | Marocco Region (S); Iberian Sea(W) | |
| | 5.5.1 Mediterranean | | |
| | 5.5.2 Black Sea | | |
| 5.6 | Atlantic North Equatorial Current Region | Trade Current Region (DK) | |
| | 5.6.1 Gulf of Mexico | ) Gulf Stream, Gulf of Mexico (W) | Gulf of Mexico (IHB) (W) |
| | 5.6.2 Bahama Waters | ) West Indian Region (S) | Bahama Sea (W) |
| | 5.6.3 Caribbean Waters | Caribbean and Yiukatan Seas (W) | Caribbean Sea (IHB)<br>Caribbean and Yukatan Seas (W) |
| | 5.6.4 Atlantic North Equatorial Current Waters | Guyana Sea (W) | |
| | 5.6.5 Cape Verde Waters | Cape Verde Region (S);Canarian Sea (W) | |
| 5.7 | Guinea Region | Equatorial Current Region (DK); Guinea Region (S)(W) | Gulf of Guinea (IHB)(W) |
| 5.8 | Atlantic South Equatorial Current Region | Trade Current Region (DK) | |
| | 5.8.1 Atlantic S. Equatorial Current Waters | Ascension Region (S) | |

| Name of the Region | Synonyms and corresponding regions by Dietrich and Kalle (DK), Schott (S), and Wüst, 1936 (W) | Geographical regions by Wüst 1939 (W) and Int. Hydrog. Bureau (IHB) |
|---|---|---|
| 5.8.2 E. Brazilian Waters<br>5.8.3 S.E. Brazilian Waters | ) Brazilian Region (S);<br>) Brazilian Sea (W) | |
| 5.8.4 Benguela Current Waters<br>5.8.5 S.W. African Waters | ) S.W. African Region (S)<br>) Angola Sea (W) | |
| 5.9 Atlantic Southern Gyrals Region | | |

TABLE 2

GROUPS OF NATURAL REGIONS OF THE OCEANS WITH SIMILAR ENVIRONMENTAL CONDITIONS

| | | Groups of similar regions (names see Table 1, locations see Figure 5 | |
|---|---|---|---|
| Polar | High Polar Regions | Group I | 2.5; 3.4 |
| | | Group II | 3.1; 3.2; 3.3 |
| Boreal | Subpolar Regions | Group III | 2.4; 4.1; 5.1 |
| | | Group IV | 4.2; 5.2; 2.3 |
| Boreal | Westwind Drift Regions | Group V | 2.1; 2.2; 4.4; 5.3.2 |
| | Subtropical | Group VI | 4.5.1; 5.4.1; 4.10.1; 5.9.1; 1.6.1 |
| | Eastern upwelling Regions | Group VII | 4.5.2; 5.4.2; 5.8.5; 4.9.4 |
| | | Group VIII | 4.6.3; 4.6.4; 5.6.5; (1.5.3?) |
| | | Group IX | 4.10.2; (1.6.2) |
| Tropical | Equatorial Current Regions | Group X | 4.6.2; 4.9.1; 5.8.1; 1.5.2 |
| | Western Subtropical Gradient Current Regions | Group XI | 5.6.1; 5.6.2; 5.6.3; 5.8.2; 1.5.1; 1.5.6; 1.3.1; 4.9.2; 4.9.3; 4.6.1 |
| | Equatorial Counter Current Regions | Group XII | 1.4; 4.8; 5.7 |
| | Indo-Pacific Monsoon Regions | Group XIII | 1.1; 1.2; 1.3; 4.7 |
| | | Group XIV | 4.3; (5.3.1) |